NASA Contractor Report 2968

Test and Development of Inflatable Spheres Instrumented With Miniaturized Thermistors, Accelerometers and Pressure Transducers

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TEST AND DEVELOPMENT OF INFLATABLE SPHERES INSTRUMENTED WITH MINIATURIZED THERMISTORS, ACCELEROMETERS AND PRESSURE TRANSDUCERS.

James K. Luers*

SUMMARY

Instrumentation for six inflatable spheres was developed, fabricated and launched to provide a better knowledge of sphere dynamics during flight and to study and investigate sphere reliability problems. Even though only one of the six launches of instrumented spheres provided telemetry data, many of the objectives of the program were achieved. Vacuum chamber tests were also conducted on spheres in a high altitude vacuum chamber to provide a better understanding of the sphere inflation problems.

Some of the results from the program are as follows. The successful performance of a two-channel instrumentation package proved that it is possible to fabricate a sub-miniature sensing and telemetry circuit (2.22 cm diameter X 7.6 cm length) that can withstand the launch, spin and ejection forces associated with the Viper Dart rocket and transmit at a distance in excess of 100 Km. Temperature data obtained from the successful launch gave evidence that: a) there is sufficient heat available in the sphere for complete vaporization of isopentane inflatent; b) the skin temperature of the sphere has minimal effect on the drag coefficient; and c) it may be possible to deduce ambient temperature from skin temperature, with reasonable accuracy below 60 Km.

The test of three spheres in the high altitude vacuum chamber gave no indication that rapid sphere inflation can cause sphere failure. Tests of residual air as a sphere inflatent were inconclusive due to failure of the vacuum pump during recompression. The test of a Super Loki type inflation capsule uncovered difficulties with the inflatent gas escaping from the capsule due to ice buildup at the orifice. Further tests of the inflation capsule as well as residual air as an inflatent are recommended.

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INTRODUCTION

A study has been conducted to provide a better understanding of the characteristics and dynamic performance of the passive sphere system in measuring the atmospheric parameters of wind, temperature, pressure and density. Over the past ten years the passive sphere technique for obtaining atmospheric measurements has established its value in providing measurements from 30 Km to 100 Km altitudes. The system is the only accurate and operational method for measurement between 70 Km and 100 Km. Universal acceptance of the system has been delayed, however, due in large part to hardware reliability problems. From the inception of the system, failures such as no inflation, catastrophic failure, or premature collapse of the sphere have resulted in an unacceptable percentage of flights that failed to provide the intended meteorological data. The cause of failures has not been reliably determined largely because of the difficulty in conducting ground tests that simulate the environment of the sphere during its ejection and descent. Several potential failure modes have been suggested. In some cases system modifications have been made based upon speculated causes of failure. One of the suggested causes was that aerodynamic heating of the dart body during ascent resulted in fusion of the mylar and prevented proper sphere inflation. A thermal insulation coating was sprayed on the dart body for protection. The insulation proved helpful in some situations but did not resolve the inflation-collapse problem. Another suggestion was that at inflation there was insufficient heat available in the system to completely vaporize the isopentane. Consequently cisbutane-2 was substituted for isopentane. The problem persisted. A suggested course of catastrophic sphere failure was the possibility that rapid sphere inflation at ejection caused structural failure of the sphere. The solution was the introduction of a pyrotechnic time delay into the inflation capsule to delay the release of gas for six seconds after ejection. Still inflation-collapse problems occurred. Other possible causes of failure that have been mentioned are: small pinhole leaks in the sphere caused by sparks or hot gases at ejection; buffeting of the sphere as it passes through Mach 1; failure of the ejection system to puncture the isopentane capsule; or the rapid despinning of the sphere when inflation occurs causes the capsule to tear the sphere skin.

Two approaches have been pursued to study the sphere hardware problem. The first approach was to design and build six subminiature sensing and telemetry circuits and to place each on board a separate sphere. These circuits would monitor the temperature, pressure and acceleration of the sphere during its descent. This data would be useful in determining the environmental changes that were experienced by the sphere and thereby establishing a better understanding of the cause of sphere failure. Skin temperature would be useful in determining if there was sufficient heat for complete vaporization of the isopentane or if aerodynamic heating of the mylar sphere during ascent caused fusing of the mylar. An internal sphere pressure measurement would be used to monitor any pressure drop from pinhole leaks or any pressure buildup in the sphere as it passes through Mach 1. An on board accelerometer would be used to measure the spin rate of the sphere and any wobble in its motion. The despinning at ejection would also be deduced from the known rocket spin rate and the spin rate of the sphere as observed, after ejection, by the accelerometer.

In addition to the use of temperature, pressure and acceleration measurements to deduce probable failure modes of the sphere these measurements could serve a second purpose of providing new information that may improve the capabilities of the passive sphere system. Skin temperature, for example, may be useful in deducing ambient temperature through the calculation of the aerodynamic and radiation heating terms. Skin temperature is also useful in determining if the temperature of the skin is sufficiently hot to have any significant effect on the drag coefficient. An acceleration profile, measured by an accelerometer, may be capable of directly providing density measurements with use of only a low precision radar.

The second approach was pursued in the sphere reliability study to perform inflation, storage, and other tests on passive spheres in an attempt to determine possible failure modes. Storage tests consisted of the unpackaging, inflation and inspection of spheres that were stored for more than two years to determine if any structural damage had occurred either in manufacture or due to the storage time. Inflation tests consisted of the ejection and inflation of three spheres in the Wallops seven-foot vacuum chamber to determine if rapid sphere inflation could cause catastrophic sphere failure. The inflation tests served a secondary purpose of assessing whether other, simplified inflation techniques could be used as an alternate means of inflating the passive spheres.

In both approaches -- instrumentation of six spheres and storage and inflation tests -- emphasis was placed not only on the discovery of potential causes of failure of the systems but also on designing and improving the systems to provide additional, or more reliable data than is available with the present passive sphere system.

Section 1 of this report describes the first approach, i.e. the fabrication launch and test results of the six instrumented spheres. Section 2 describes the second approach, the results of the other tests that were performed on passive spheres. Summary and conclusions for the entire research program are contained in Section 3.

SECTION 1
MINIATURIZED INSTRUMENTATION OF SPHERES

Inflight measurements of the temperature, pressure and acceleration profiles would provide a better understanding of the dynamics of the passive sphere system and could also be useful in deducing additional meteorological information not presently available from the passive sphere system. Reference 1 describes the type of information that can be obtained from an instrumented sphere and the technical feasibility of instrumenting such a sphere. Briefly the utility of sphere skin temperature, internal sphere pressure, and vertical acceleration profiles is as follows.

1.1 SKIN TEMPERATURE

To some degree the drag coefficient for a sphere is a function of the temperature of the skin. A measurement of skin temperature will allow the inclusion of this effect, if it is significant, in a density calculation or will justify the common procedure of ignoring this effect.

The temperature of the skin is influenced by radiation, by aerodynamic heating, and by the ambient temperature of the atmosphere. If the radiation and aerodynamic heating terms can be accurately evaluated, then the temperature of the atmosphere can be derived. Two independent temperature measurements, one deduced from the skin temperature (not influenced by vertical motion of atmosphere), the other from the radar track (influenced by vertical motion), would allow the measurement of vertical motion in the atmosphere.

The temperature of the sphere skin at ejection from the rocket would be useful in determining whether sphere failure can result from fusing of the mylar due to aerodynamic heating of the rocket during ascent.

Shortly after ejection, heat is extracted from the skin in order to vaporize the isopentane. If insufficient heat is available, then not all the isopentane will vaporize and the resulting lower internal sphere pressure would result in premature sphere collapse.

1.2 PRESSURE

A differential pressure transducer that measures the difference between the internal sphere pressure and the ambient pressure would be useful in assessing the structural integrity of the sphere. If the sphere leaks, or if it deforms at Mach 1 then pressure variations could be measured by a differential transducer. This data would be useful in troubleshooting sphere failure problems.

1.3 ACCELERATION

A single axis accelerometer could, if the proper sphere orientation is known, measure the drag acceleration of the sphere. This along with a low precision radar, could be used to deduce atmospheric density. Presently a high precision FPS-16 tracking radar is required to determine the acceleration of the sphere.

Of the three measurements, the skin temperature has the most potential for operational use on the passive sphere. In addition, the cost for thermistors is on the order of a few dollars as compared to several hundred dollars for miniaturized pressure and acceleration transducers. There is also some question, concerning whether state-of-the-art accuracy of pressure and acceleration transducers is sufficient to produce the intended results.

1.4 DESIGN SPECIFICATIONS

In order to instrument a passive sphere with sensors and telemetry that was packaged inside the payload compartment of a meteorological rocket and that would withstand the launch and ejection forces of the rocket, severe design contraints were necessary. These constraints are as follows.

a. Size of the instrumentation package, including batteries must be less than 2.54 cm in diameter and 8.89 cm in length.

b. Total mass of instrumented sphere must be less than 200 grams. Instrumentation therefore must be less than $\approx$ 80 grams.

c. All instrumentation must withstand forces produced by the 40 rps ascent spin of the rocket.

d. All instrumentation must withstand a 400 g ejection force.

e. Telemetry must be maintained for twelve minutes of flight under potentially extreme temperature conditions.

f. Thermistors must measure temperatures accurate to $\pm 2^{\circ}C$ over the range from $-60^{\circ}C$ to $+30^{\circ}C$. A fast time constant is also desirable.

g. Differential pressure transducer must measure to an accuracy of 1 mb on a scale from 0-15 mb.

h. Differential pressure transducer must be sufficiently rugged, small and light weight to satisfy requirements a, b, c, and d.

i. Single axis accelerometer must measure to an accuracy of $\pm$ 0.2 g on a range of 0-5 g.

j. Accelerometer must be sufficiently rugged, small and light weight to satisfy requirements a, b, c, and d.

With these restrictions in mind, telemetry and sensing circuits were designed that could be incorporated into the passive sphere system.

Both two-channel and four-channel sensing circuits and a transmitter circuit were built and flown. The two-channel circuit, being of simple design with less potential sources of failure, was used in the first launch. After that successful launch additional four-channel systems were designed and flown in order to provide for the measurement of two more sphere parameters. In all, six launches were made, two with the two-channel systems on board and the remaining four with four-channel systems. A single transmitting circuit that could be used with the two- or four-channel sensing circuits was developed for telemetry of data to a ground receiving station. Description and schematics of the two- and four-channel sensing circuits, the transmitting circuits, the sensors, and assembly and packaging techniques are contained in the following sections.

1.5 DESIGN OF THE TWO-CHANNEL TELEMETRY SYSTEM

The two-channel telemetry system, shown in Figure 1, was designed so that the pulse-length of the transmitted pulse represents the temperature data from thermistor one (RT-1) and the elapsed time between pulses represents the temperature data from thermistor two (RT-2). This was accomplished through the use of two multi-vibrators (IC-1 and IC-2) coupled together so that the trailing edge of the pulse of IC-1 triggers the leading edge of the pulse of IC-2, and the trailing edge of IC-2 triggers the leading edge of IC-1. When IC-2 enables IC-1, it holds the transmitter on for the duration of time determined by the RC network consisting of R_1, R_2, C_1, and RT-1 (thermistor one). At the end of its cycle it triggers IC-2 which holds the transmitter off for the duration of time determined by the RC network consisting of R_3, R_4, C_2, and RT-2 (thermistor two). The resistor R_1 (or R_3) assumes a known pulse length in the event of a broken thermistor. The resistor R_2 (or R_4) provides a known pulse length in the event of a shorted thermistor.

As there are no timing circuits involved, the sampling rate of the system is determined by the temperatures being measured by the thermistors. The higher the temperatures being measured the shorter the pulse-lengths and consequently, the higher the sampling rate frequency.

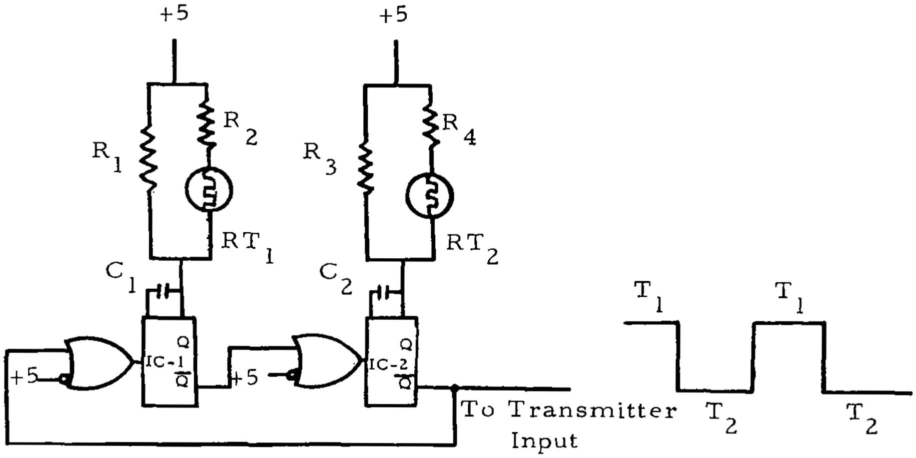
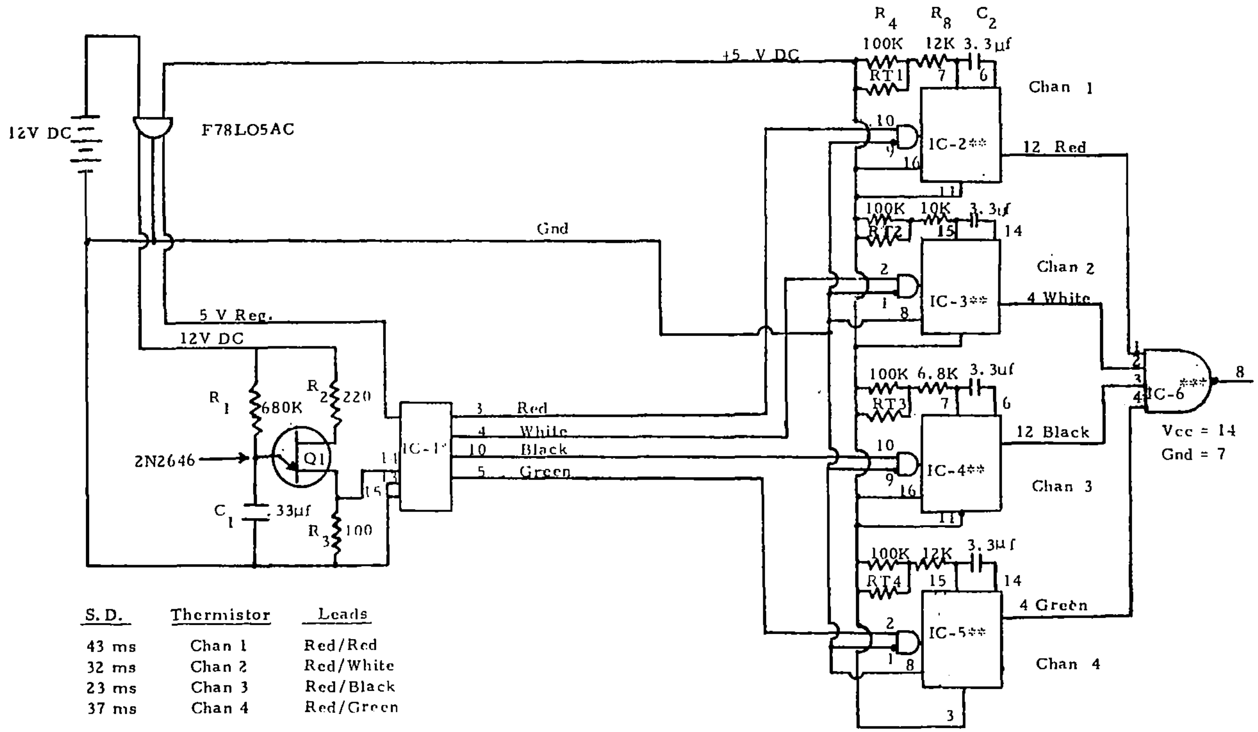


Figure 1. Two-Channel System

1.6 DESIGN OF THE FOUR-CHANNEL TELEMETRY SYSTEM

The four-channel telemetry system was designed in two basic configurations. The first configuration, shown in Figure 2, is used for transmitting temperature data from four thermistors located at various points on the sphere. The clock pulse used to control the rate at which the data is sampled in each of the four channels is produced by Q1 with the frequency being determined by the RC network consisting of R_1 and C_1. For this system the clock pulses are calculated to occur approximately 200 milli-seconds apart. The pulses are fed to the counter/divider circuit (IC-1), which produces a pulse to enable each of the four channels in sequence. By using alternate outputs of the counter/divider circuit, each channel is enabled for 400 milli-seconds during its allotted sampling period.

For the sake of simplicity only the operation of channel one will be discussed as the operation of each individual channel is identical. When the multi-vibrator (IC-2) is triggered by the enabling pulse from IC-1, it produces an output with a pulse-length directly proportional to the temperature of the thermistor (RT-1). The calibration of the pulse-length is determined by the RC network consisting of R_4, R_8, RT-1, and C_2. Because of the difficulty in receiving extremely short pulses (which would occur if the thermistor shorted), and of the possibility of the pulse of one channel overlapping the pulse of the succeeding channel in the event that a thermistor should open; the system was designed so that the minimum pulse-length would be limited to 50 milli-seconds and the maximum pulse-length would be limited to 350 milli-seconds. This was accomplished by the insertion of the series resistor R_8 (which limits the minimum pulse-length), and the parallel resistor R_4 (which limits the maximum pulse-length). This pulse is then fed to a buffered output (IC-6) which insures that the pulses from each of the four channels is of the correct



S. D.	Thermistor	Leads
43 ms	Chan 1	Red/Red
32 ms	Chan 2	Red/White
23 ms	Chan 3	Red/Black
37 ms	Chan 4	Red/Green

*IC-1 part number MC14017CP
**IC-2, -3, -4, -5 part number MM74C221
***IC-6 part number MM74C30N

Figure 2. Four Channel System; 4 Thermistors, RT-1 - RT-4.

amplitude and polarity to properly trigger the transmitter. The conditioned pulse from IC-6 is fed directly to the input to the transmitter.

The second configuration, shown in Figure 3 is basically identical to the first with the exception that channel two has been modified to accept a bridge type transducer (typically a pressure transducer, ozone detector, or an accelerometer). The output of the transducer is applied to a differential amplifier (IC-7), which amplifies and interfaces the signal to the multi-vibrator (IC-3). The pulse-length is determined by the RC network consisting of R_{12} and C_6. Where the pulse-length was dependent on variations of resistance in the thermistor in the first configuration, it is now dependent on variations in voltage supplying the network. The remainder of the circuit is identical to that described in the first configuration.

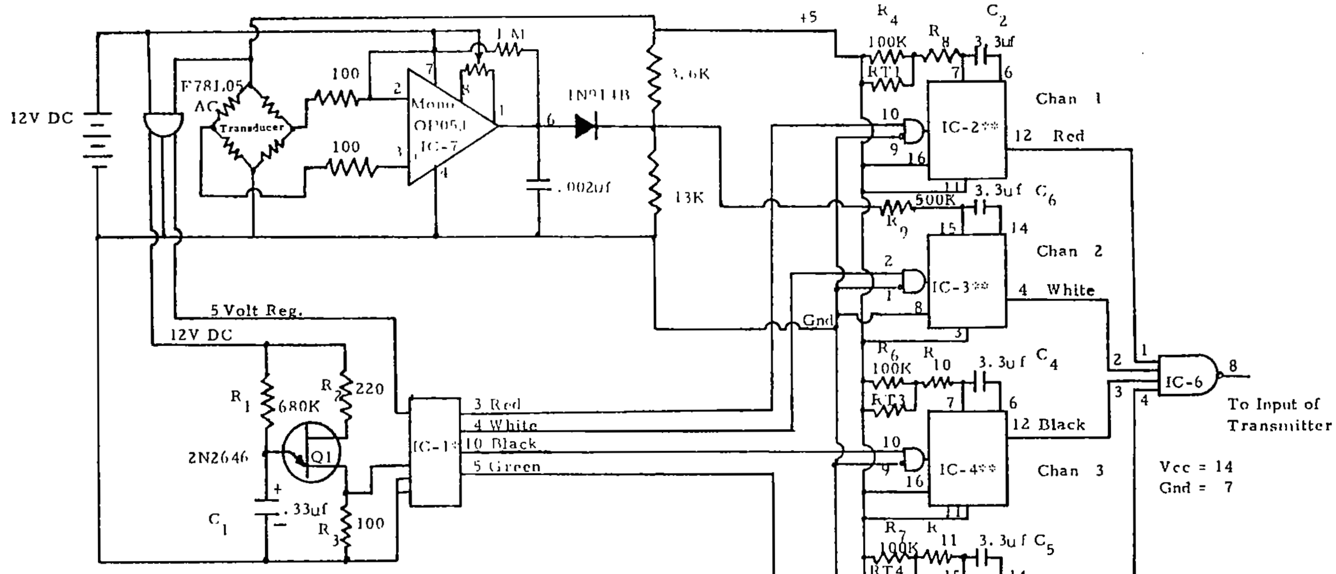
1.7 DESIGN OF THE TRANSMITTER

The transmitter is a modified Hartley transistorized oscillator whose output is capacitively coupled to a half-wave antenna positioned within the sphere.

The output of the two- or four-channel telemetry system (+5 volt pulses whose pulse-length represents the data to be transmitted) is applied to the transmitter input at R_1 (Figure 4). The +5 volt pulses at R_1 forward bias Q1 providing excitation to the tuned circuit consisting of C_4 and L_1. For the purposes of this project the oscillator was tuned to approximately 219.45 MHz with an output power of approximately 200 milliwatts to be compatible with the radio receiving equipment at the test facility. The transmitted signal is comprised of a burst of 220 MHz R-F energy, the length of which corresponds to the length of the input pulse.

Power for the system is provided by two 6 volt Union Carbide* silver-oxide batteries in series. The resultant 12 volts is applied to an F78L05AC 5 volt

*The use of trade names in this report does not constitute an official endorsement or approval of the use of such commercial hardware or software. This report may not be cited for purpose of advertisement.



Thermistor	Leads
Chan 1	Red/Red
Chan 2	Red/White
Chan 3	Red/Black
Chan 4	Red/Green

*IC-1 part number Mc14017CP
**IC-2, -3, -4, -5 part number MM74C221

Figure 3. Four-Channel System; 3 Thermistors, 1 Transducer.

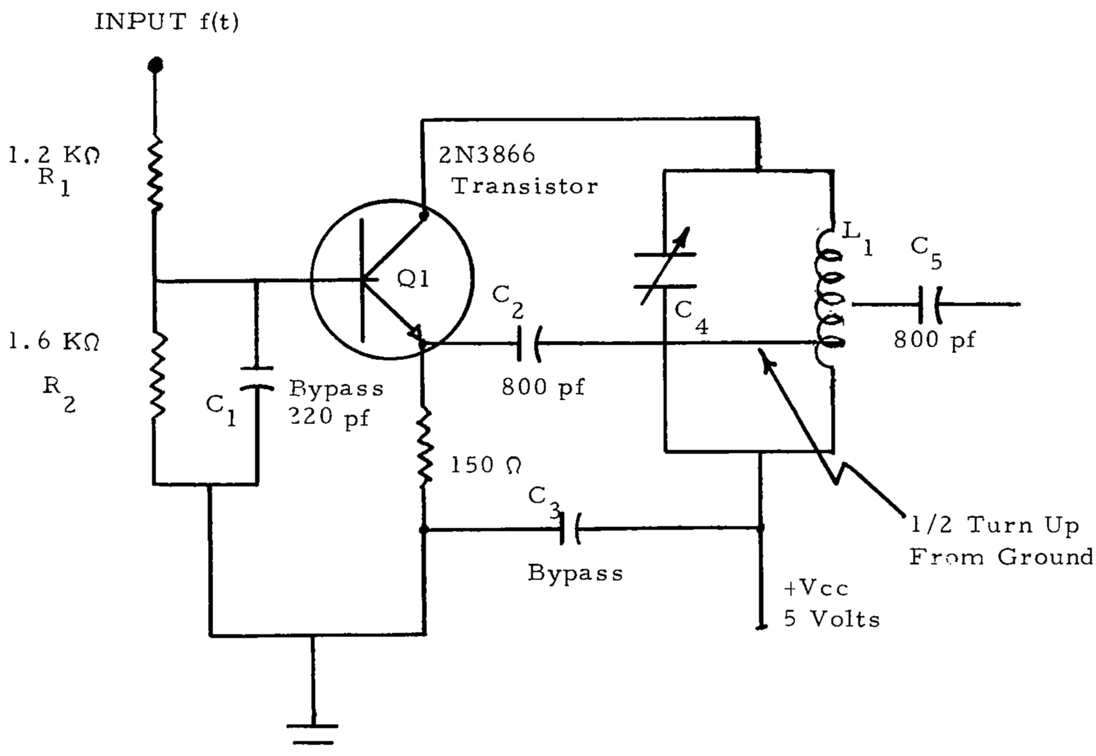


Figure 4. Transmitter Circuit

regulator which supplies the system with a constant 5 volts throughout the flight.

1.7.1 Test of Batteries

The choice of batteries to power the transmitter was made after testing various types for power output at both high ($\approx 30^{o}C$) and lower temperatures ($\approx 0^{o}C$). Laboratory tests were made of battery output versus time for several different types of batteries. Those tested were: Nickel-Cadmium; Alkaline; Silver-Oxide; Mercury; and Carbon Zinc. Lithium batteries were also considered but not tested because of the large size battery needed to provide adequate voltage. The design goal of the test was to find a battery capable of supplying 200-300 milliwatts of power for 12 minutes at approximately zero degrees centigrade. The battery also had to be sufficiently small to be packaged within the 2.54 cm diameter by 8.89 cm length available packaging space for instrumentation. High voltage was also desirable in a battery.

Tests of batteries were conducted at approximately $0^{o}C$ and at room temperature. The $0^{o}C$ tests were made by submerging the batteries in ice water for 15 minutes prior to the tests. Results of the tests are shown in Table 1.

The nickel-cadmium battery was low voltage and did not provide sufficient power at $-5^{o}C$. Its large size prohibited the use of multiple cells.

Two different size alkaline batteries were tested: a 3 volt and a 4.5 volt. The former was tested at about $-4^{o}C$ and the latter at room temperature. The tests showed the alkaline batteries provided good power at room temperature but poor output at low temperatures. Also the alkaline batteries were rather large and heavy.

Two sizes of silver-oxide batteries were tested as well as a stacking of three of the smaller cells in series. The six volt batteries provided good output ($\approx$250 mw) at room temperature with a reduced output ($\approx$65mw) after 12 minutes at $-4^{o}C$. A

TABLE 1. -BATTERY TEST RESULTS

BATTERY							TEST DATA			
							Output at End of 12 Min.		Test Condition	
Manufacturer	Cell	No.	Electrolyte	Dia. (cm)	Length (cm)	Voltage (volts)	Voltage (volts)	Power (mw)	Initial Temp. (^{o}C)	Load (Ω)
Union Carbide	CH500	1	NiCad	1.43	5.08	1.25	1.17	91.0	- 4.5	15.0
Union Carbide	CH500	2	NiCad	1.43	5.08	1.25	1.20	48.0	- 5.0	30.0
Mallory	PX30	1	Alkaline	2.38	1.11	3.00	2.43	82.0	- 4.8	72.0
Mallory (second run)							0.10	0.6	- 4.0	15.0
Union Carbide	523	1	Alkaline	1.59	4.92	4.50	3.75	562.0	23.0	25.0
Union Carbide	544	4	Silver	1.27	2.54	6.00	3.12	61.0	- 5.0	160.0
Union Carbide (second run - 1-1/2 hour recovery)							2.60	42.0	- 4.0	160.0
Union Carbide	544	3	Silver	1.27	2.54	6.00	3.41	73.0	- 4.4	160.0
Union Carbide	544	2	Silver	1.27	2.54	6.00	5.20	224.0	25.0	120.7
Union Carbide	544	1	Silver	1.27	2.54	6.00	4.48	278.0	25.0	72.1
Union Carbide	S41E	5A	Silver	1.11	0.48	1.50	0.57	9.3	- 3.3	35.0
Union Carbide	S41E	4	Silver	1.11	0.48	1.50	1.21	29.0	0.0	50.0
Union Carbide	S41E	3A	Silver	1.11	0.48	1.50	0.32	4.6	0.0	22.1
Union Carbide	S41E	2A	Silver	1.11	0.48	1.50	0.29	3.8	0.0	22.1
Union Carbide	S41E	1-3	Silver	1.11	1.44	4.50	4.00	160.0	24.0	100.0
Union Carbide	S41E	4-6	Silver	1.11	1.44	4.50	2.96	188.0	25.0	46.6
Mallory	TR1G3	1	Mercury	1.75	3.33	4.20	2.98	88.7	23.0	100.1
Mallory	TR1G3	2	Mercury	1.75	3.33	4.20	1.15	57.5	23.0	25.0
Union Carbide	504	1	Carbon Zinc	1.59	3.49	15.00	2.80	22.0	- 4.5	360.0
Union Carbide	504	2	Carbon Zinc	1.59	3.49	15.00	7.20	148.0	25.0	351.0

Alkaline - Manganese Alkaline
Mercury - Mercuric Oxide
NiCad - Nickel Cadmium
Silver - Silver Oxide

retest of one of the batteries after a one and one-half hour recovery period produced 42 mw after 12 additional minutes. It should be emphasized that the output power shown on Table 1 is at the termination of the 12 minute tests. Often the power output is considerably higher throughout the test and only drops off near the end of 12 minutes.

The subminiature 1.5 volt silver-oxide batteries did not perform satisfactorily at low temperatures except under a light load (50 Ω). A combination of three of these cells in series provided good output at room temperature but was not expected to improve on the 6.0 volt silver-oxide at low temperatures.

A rather large 4.2 volt mercury battery was also tested. Its output at room temperature was inferior to the silver-oxide batteries. The size of the mercury battery made it impractical for more than one to be used in the instrumentation package.

The 15 volt carbon zinc battery provided insufficient power at low temperatures and questionable power at room temperature. Its size inhibited the use of more than one cell in a package. Overall it was not as good as the silver-oxide batteries.

The final battery chosen was the 6.0 volt silver-oxide battery. The battery did not provide the design goal of 200 mw power for 12 minutes at $0^{\circ}C$. It did however provide this output at warmer temperatures as well as at $0^{\circ}C$ for shorter lengths of time. Since it performed best of all the batteries tested and furthermore, since the temperature environment of the battery during a flight duration was unknown, this battery was chosen for use in the instrumentation package. It was small in size and allowed two cells to be included in the instrumentation. It served as the power source for both the transmitter and sensing circuits.

1.8 SENSORS

1.8.1 Type of Thermistors

Three different thermistor types were used for sphere skin temperature measurements. The purpose of using more than one type thermistor was twofold. First, comparison of results from thermistors with different time constants would determine if a thermistor with a fast time constant was needed. Second, the performance and ruggedness of the different makes and sizes of thermistors could be evaluated. In general, miniaturized thermistors with fast time constants were very delicate and required special handling.

The three thermistors chosen for use on the various flights were a VECO #FN2B42, Fenwall #GB42MC1, and Yellow Spring Instrument (YSI) #44006. The VECO has a very delicate attachment of lead wires to the thermistor. Its time constant in still air is .2 milliseconds. The Fenwall is a glass bead thermistor with lead wires first entering a glass rod attached to the thermistor. Its length is .64 cm and breakage of the glass requires little force. Its time constant in still air is 1 second. The YSI is a considerably larger, more rugged bead thermistor with large lead wires. Its time constant in still air is 10 seconds. Accuracy of all thermistors is within the 2°C design specifications. A calibration curve was derived between -40°C and +30°C for each individual thermistor flown.

1.8.2 Accelerometer

The accelerometer determined to best satisfy design specifications was a subminiature single axis Kulite model #GY-125 accelerometer. Its dimensions were .76 cm X .38 cm X .33 cm and could easily be imbedded in the instrumentation package. The acceleration range was 0 to +10 g and had absolute accuracy of approximately 0.1 to 0.2 g. Since inflight calibration at apogee was feasible (at apogee $\ddot{z} = g$) the acceleration measurement could be made considerably more accurate than the .1 g to .2 g range.

Each accelerometer was tested and calibrated prior to packaging. Calibration curves were derived for each accelerometer under different temperature conditions. The thermal sensitivity, zero shift, and linearity were all within design specifications. The accelerometer was imbedded in the instrument package so that the sensitive axis of the accelerometer was in a horizontal position when placed in the rocket payload compartment. In this configuration the only launch force observed on the sensitive axis of the accelerometer was the force induced by the spin of the rocket. By placing the accelerometer near the spin axis of the rocket the magnitude of this force was calculated to be less than the 200% over- range tolerance of the accelerometer. After ejection, when the sphere is inflated, the sensitive axis of the accelerometer is positioned along the line between the center of pressure and center of mass of the sphere. With this alignment, when the sphere is in a non-oscillating equilibrium position, the accelerometer measures the drag acceleration on the sphere.

1.8.3 Pressure Transducer

Two miniaturized pressure transducers were tested and evaluated for use with the four-channel sensing circuit, a Kulite model #CHQ-125-5 and a Sensotec Type F transducer. The size of each transducer was less than .51 cm on a side. Differential pressure transducers were used with a rated pressure range 0 to 5 psi (330 mb). This was the smallest pressure range available and dictated the use of a high gain amplifier to magnify the output in the 0-20 mb range where measurements were expected. Design specifications for each transducer indicated error sources of up to 15 mb for zero balance and $\pm$ 10 mb for a temperature change of

$55^{\circ}C$. The zero balance could be compensated by inflight calibration since the differential pressure is zero at sphere collapse.

Laboratory tests of thermal drift for both Kulite and Sensotec transducers were discouraging. The Kulite transducer showed a drift of 30% of full scale (0-20 mb) resulted from a temperature variation of $50^{\circ}C$. Sensotec transducers showed even larger drift problems and were judged unsuitable for use. The problem appeared to be that a large warm-up time was needed to stabilize the Sensotec recordings. Tests at the University of Dayton Research Institute (UDRI) indicated stabilization occurred only after 20 minutes of warm-up time.

Even though the inflight accuracy attainable with each transducer was highly questionable it was decided to launch two systems with pressure transducers - one a Kulite and one a Sensotec - and to place a thermistor in the immediate vicinity of the diaphragm of the transducer to monitor temperature. The temperature trace was to be used to compensate for the thermal drift effects on the transducer.

1.9 CIRCUIT ASSEMBLY

The sensing and transmitting circuits were fabricated and attached to the inflation capsule according to the schematic of Figure 5. Two 6.0 volt batteries were placed adjacent to the inflation capsule, followed by the sensing circuit then the transmitter, in that order. The two-channel circuit was mounted on two 2.22 cm diameter etched boards, while the four-channel system required four. The entire instrumentation package was potted in RTV-615, a transparent resillient plastic. The RTV also served as an adhesive to hold the instrumentation package onto the inflation capsule. Wires which go to the sensors, and the antenna wire, protruded

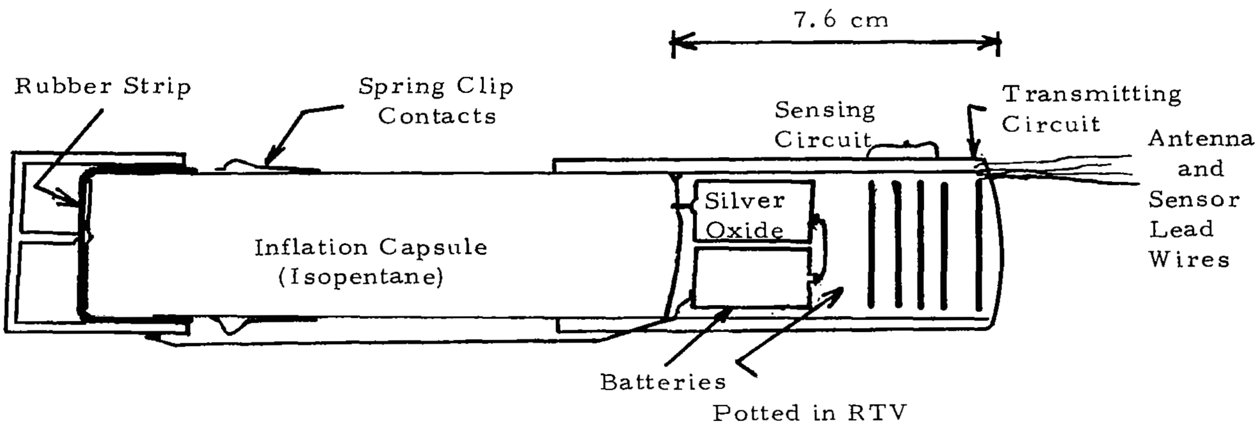


Figure 5. Capsule; Sensing And Transmitting Circuit Assembly

through the RTV at a common point. An additional wire, used to activate the electronics, connected the batteries to the cap on the inflation capsule. The cap was electrically insulated from the inflation capsule by a strip of rubber. When the capsule was punctured at ejection the cap made contact with the spring clips, completed the circuit, and activated the electronics.

1.10 ATTACHMENT TO SPHERE AND PACKAGING

Six specially made ROBIN spheres with two clear gores, in contrast to the standard configuration of all metalized gores, were purchased from Space Data Corporation. The clear gores were positioned 180° opposite one another. Inflation capsules of the type used with the Viper Dart rocket were also purchased. The transmitter and sensor circuits were fabricated on circular boards, potted and attached to the inflation capsule with RTV as previously shown in Figure 5. The capsule with instrumentation was rigidly attached to the sphere as shown in Figure 6. The sphere was reinforced with an additional piece of mylar in the region where the capsule was attached. The capsule was taped at three points to the reinforced part of the sphere with heat sensitive tape. Antenna and thermistor lead wires were attached to the inside of the sphere skin with non-conducting heat sensitive tape. The antenna wire was taped along the entire length of one of the clear gores. The other clear gore (located 180° opposite) served as a second radiation window.

Thermistors were mounted on 1.91 cm wide transparent tape as shown in Figure 7. Stiffeners consisting of short steel rods were placed alongside the Fenwall and VECO thermistors to protect them from damage. The stiffeners were located at a sufficient distance from the thermistor so that the heat transfer from stiffener to thermistor had a negligible effect on the thermistor temperature. A second piece of double adhesive transparent tape was placed over the thermistor to electrically insulate the lead wires from contact with the metalized skin. A small

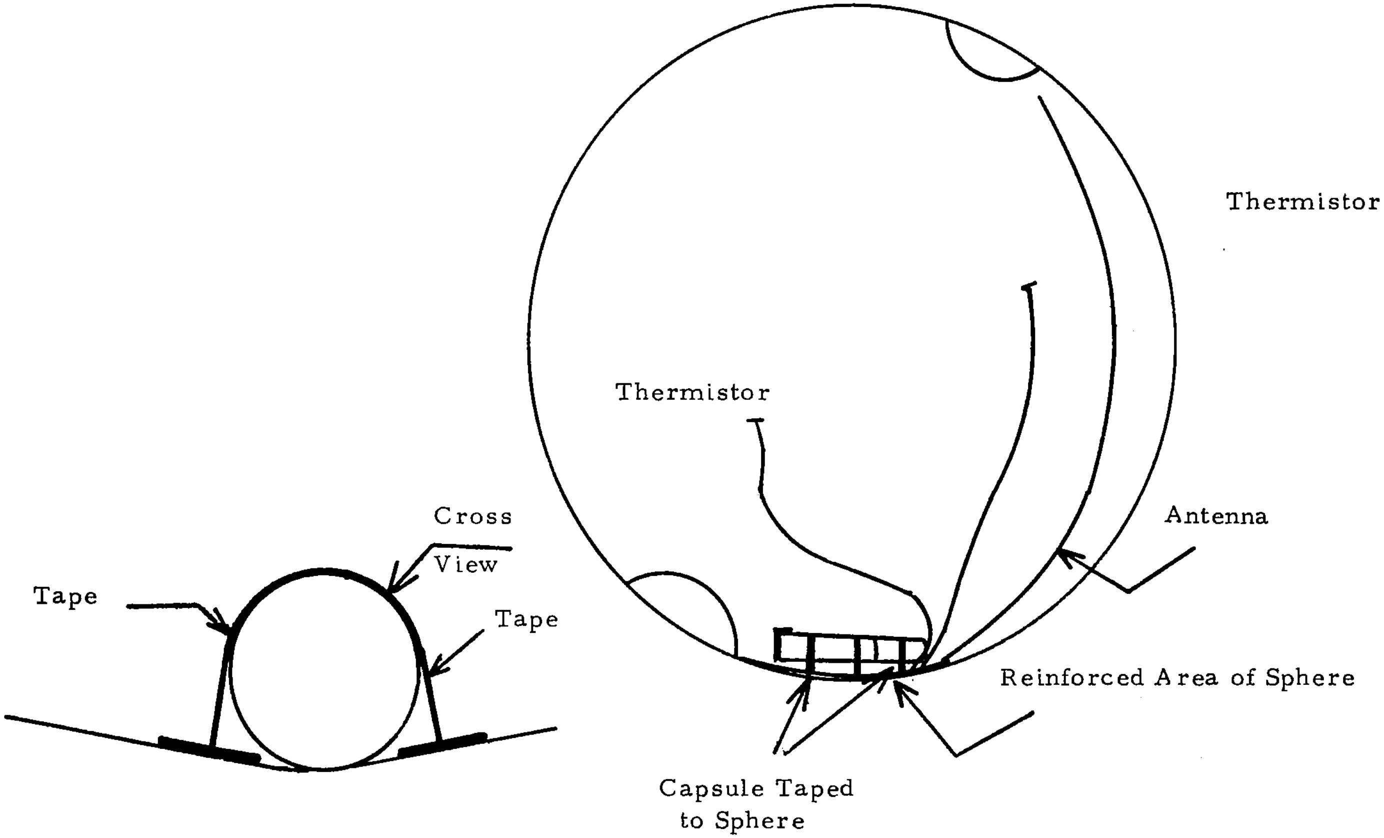


Figure 6. Attachment of Capsule to Sphere

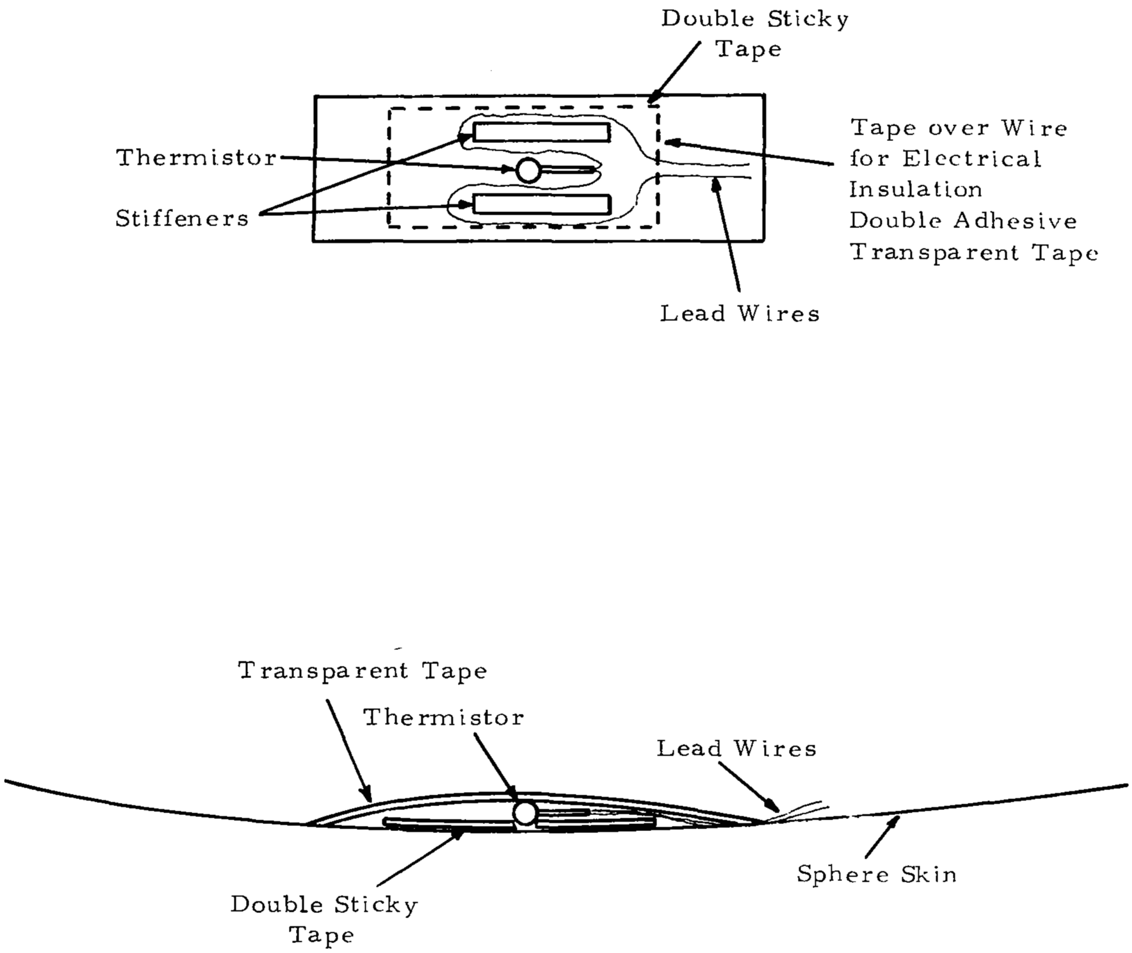


Figure 7. Mounting Of A Fenwall Thermistor

hole was made in the tape at the bead of the thermistor so that thermistor contact would be made with the skin of the sphere. The tape containing the thermistor was then fixed to the inside skin of the sphere. A piece of aluminized mylar skin was attached to the back of the tape so that the thermistor was sandwiched between pieces of aluminized mylar skin. Powder was applied to the area of attachment to neutralize any uncovered adhesive remaining.

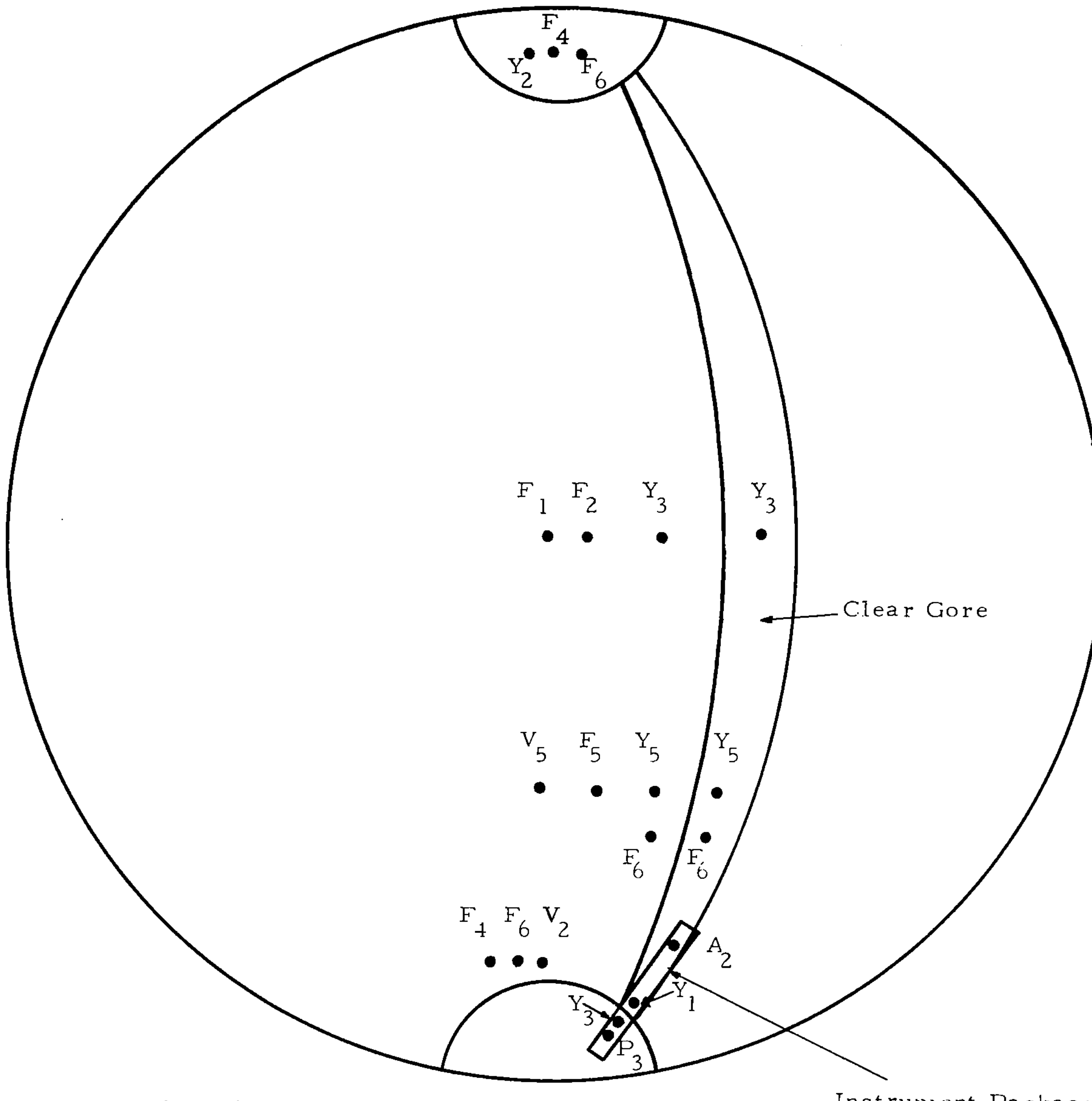
Locations of thermistors on the sphere were varied from flight to flight as a means of deducing dynamic sphere and thermistor behavior. The various locations of thermistors, pressure and acceleration transducers are shown by flight number in Figure 8. When an accelerometer or pressure transducer was used with a four-channel system the transducer was imbedded in the instrument package. For the differential pressure transducer the reference tube protruded outside of the RTV. When attached to the sphere, the reference tube was passed through the skin, and sealed, so as to sense external pressure. After the instrumentation and sensors were attached to the sphere it was evacuated and placed inside the dart body.

1.11 TESTS PERFORMED ON BALLOON AND INSTRUMENTATION CAPSULE

Throughout the research program numerous tests of the sphere and instrumentation capsule were made to evaluate the performance of various components under simulated flight conditions. Some tests were performed prior to the first launch while others were made after different launches to evaluate potential causes of telemetry failure. Results are as follows.

1.11.1 Thermal Tests

A thermal test was made on each electrical component before it was used in the design of a sensing or transmitting circuit. The test consisted of checking the performance of each component before and after being placed in a low temperature ($-40^{\circ}C$) and high temperature ($+80^{\circ}C$) environment. All components



Y - YSI Thermistor
F - Fenwall Thermistor
V - VECO Thermistor
A - Accelerometer
P - Pressure
Subscripts 1, 2, . . . 6 refer to the Flight Number

Figure 8. Location of Thermistors and Transducers by Flight Number

used in the design of a circuit passed these tests. Additional thermal tests were made on each system after fabrication and potting. A potted instrumentation capsule was placed in a high and low temperature environment, the sensing circuits activated, and the thermistors, accelerometer and transducer calibrated throughout the temperature range. Temperature correction curves were obtained for all systems which did not perform within specifications as the temperature was varied. Temperature data transmitted from a thermistor located in the instrument package near a transducer could then be used to correct for temperature related drift.

1.11.2 Inflation Test

In the packaging process an interesting discovery was made concerning the passive sphere. In evacuating each of the six spheres, a completely airtight sphere was never found. When the vacuum was removed and the sphere sealed, a slight amount of air always entered into the sphere. Originally a hole or unsealed tape was suspected. Several balloons were inflated until taut and floated in a water bath to search for leaks. Some leaks along the tape were found, primarily where sealing of the final gore by hand iron was done at UDRI. After these leaks were sealed however, the balloons still would not contain significant superpressure. It is suspected that perhaps some diffusion through the skin or tape causes the balloons not to be completely airtight. This would explain why a vacuum or significant superpressure cannot be maintained inside a sphere. The inability of a sphere to maintain superpressure during its flight path descent could result in a small mass loss and thus produce premature collapse.

1.11.3 Shock Test

Prior to launch of the first two-channel system a test was made of the instrumentation capsule to assess its ability to withstand an ejection force of 400 g. A drop test was performed at Wallops Flight Center by mounting a capsule with attached instrumentation potted in RTV on a pedestal and dropping from a height that produced a 400 g shock at impact. The results of the first test were inconclusive since some damage was found after the test but it could not be conclusively determined whether the damage resulted from the test or occurred during mounting. A repeat of the test performed after Flight 4 showed no damage to the transmitter or sensor circuits resulted from the shock test.

1.11.4 Conductivity Test

A skin conductivity test was performed after the failure of Flight 3 to receive telemetry data. The purpose of the conductivity test was to determine if battery discharge was occurring during storage by electrical leakage through the aluminized skin. The instrumentation was activated at ejection when the cap on the inflation capsule touched the contact points attached to the body of the capsule. Activation of the instrumentation could have occurred during storage if electrical contact was made between the cap and capsule. A possible way for this to have occurred is as follows. The cap was covered with a clear piece of mylar to insulate it from the aluminized skin. A small area, approximately .5 cm by .5 cm was cut out of the center of the mylar to allow the isopentane easy escape into the sphere. When, in packaging, the sphere was evacuated, it may have been possible for the cap to come in contact with the aluminized skin through this hole. The instrumentation would then be activated if conductivity existed through the aluminized skin to the body of the capsule. To test the conductivity path, an experiment was performed on segments of a sphere to determine the skin resistance. Using a 15 cm separation between electrodes placed in contact with the aluminized side of the skin, extreme differences in resistance were found. Values of resistance between 4000 Ω and 100,000 Ω were found for different segments of the skin. For a given skin segment relatively little difference in resistivity was obtained by tracing out a circular path of 15 cm radius with one electrode at the center. The results of this test indicate that the conductivity of the skin is relatively constant for a given segment but may vary considerably for different segments of the sphere. At the low resistance values (≈ 4000 Ω) electrical conductivity would be sufficient to activate the system and discharge the batteries while in storage. The high resistance values would not be capable of discharging the batteries.

The conclusion from the tests is that it is possible that electrical conductivity through the aluminized skin discharged the batteries prior to launch. However, it is remote that this was the cause of any system failures for several reasons. a) The same defect was present in a system which transmitted successfully. b) Electrical contact would be required over an extended length of time. It is unlikely that sufficient vacuum would remain in the sphere to maintain good contact. c) Only certain areas of the skin have sufficient conductivity to activate the system.

1.11.5 Packaging Test

After Flight 5, a packaging test was performed to determine if instrumentation failure could have resulted from breakage of instrumentation during packaging. The test consisted of evacuating, folding, squeezing and packaging of a two-channel system into the staves of the dart, as though it were to be launched. The sphere was then removed from the dart, unfolded and tests made of the transmitting and sensing circuits. All circuits performed satisfactorily. No breakage of sensors, transmitter or other damage was observed. To further reduce compression forces during packaging, slightly smaller molds were fabricated for potting of the instrumentation in RTV. The molds, approximately .15 cm smaller were used for Flight 6.

1.11.6 Vacuum Test

After Flight 5, a vacuum test was made of an RTV potted instrument package by placing it inside a small vacuum chamber and rapidly evacuating the chamber. The purpose of the test was to see if bubbles in the RTV, when subjected to vacuum conditions, outgassed and caused rupture or damage to the instrumentation package. Results from the test showed no damage due to vacuum conditions.

1.11.7 Transistor Test

After Flight 5, several different types of transistors were purchased and tested for improved performance as oscillators in the transmitter circuit. The tests were designed to determine if capacitance feedback from the surrounding environment would have less influence on the new transistors than on the one presently used. Tests with varying input voltage were made with different objects providing feedback to see which transistors performed best. No outright superior transistors were found. Some performed as well as the presently used transistor. Those that did performed satisfactorily under all adverse conditions simulated.

1.12 REDUNDANT SWITCHES

After launch of the fifth system it was suspected that the telemetry failure could be due to the malfunction of the switch used to turn on the transmitter. Consequently, the sixth launch and a seventh system, not yet flown, were modified to include a redundant switch wired in parallel with the cap switch. The sixth instrument package was equipped with a microswitch in addition to the cap switch. The spring loaded microswitch was molded into the RTV and held in the off position by the compression force of the staves on the lever arm of the microswitch. At ejection, when the sphere was inflated, the spring loaded lever arm was free to retract and activate the instrumentation. Ground tests of the switch indicated it to be very reliable.

The seventh system was built with a magnetic reed switch which remained in the off position when in the vicinity of a magnetic field. When the magnetic field was removed, the switch activated the system. Removal of the magnet was planned immediately prior to launch. Since this procedure was not in conformance with Wallops

Flight Center range safety requirements, this system was not launched, a future launch is planned with attempted sphere recovery after the magnetic switch is removed from the system.

1.13 RESULTS OF LAUNCHES OF INSTRUMENTED SPHERES

Flight #1

Two-Channel System:	Viper Dart Rocket, Sphere Mass = 149 grams
Two Thermistors: (see Figure 8)	Fenwall - 90° from south pole on metalized gore YSI - embedded in instrumentation package
Launch Date:	03 October 1975
Launch Time:	17:45 Zulu
Test Objectives:	• To test and evaluate the performance of the two-channel system. • To provide a measurement of skin temperature at one location on the sphere. • To measure temperature of instrumentation package for assessment of battery performance.
Results:	The launch of the first system was a complete success. The telemetry signal was found within 45 seconds after ejection and produced accurate temperature profiles from both thermistors between 100 to 32 Km. Figure 9 shows skin temperature and instrumentation temperature profiles from the flight. Also shown is the temperature profile obtained from the radar track of the sphere using the drag coefficient, hydrostatic, and gas laws (see Reference 2). Assuming accurate drag coefficients, this temperature profile (sphere C_D profile) provides a measure of the ambient atmospheric temperature. In addition to the sphere C_D temperature profile, another has been obtained from a datasonde thermistor flight launched shortly before the sphere. Analysis of Figure 9 and other data from the flight has revealed the following information. a. The skin temperature of the sphere is biased on the warm side relative to both the datasonde and the sphere (C_D) profiles. This reflects both radiant and aerodynamic heating of the sphere. Between 32 and 55 Km the skin temperature is approximately 17° to 20° warmer than the C_D temperature profile. The apparent cause is

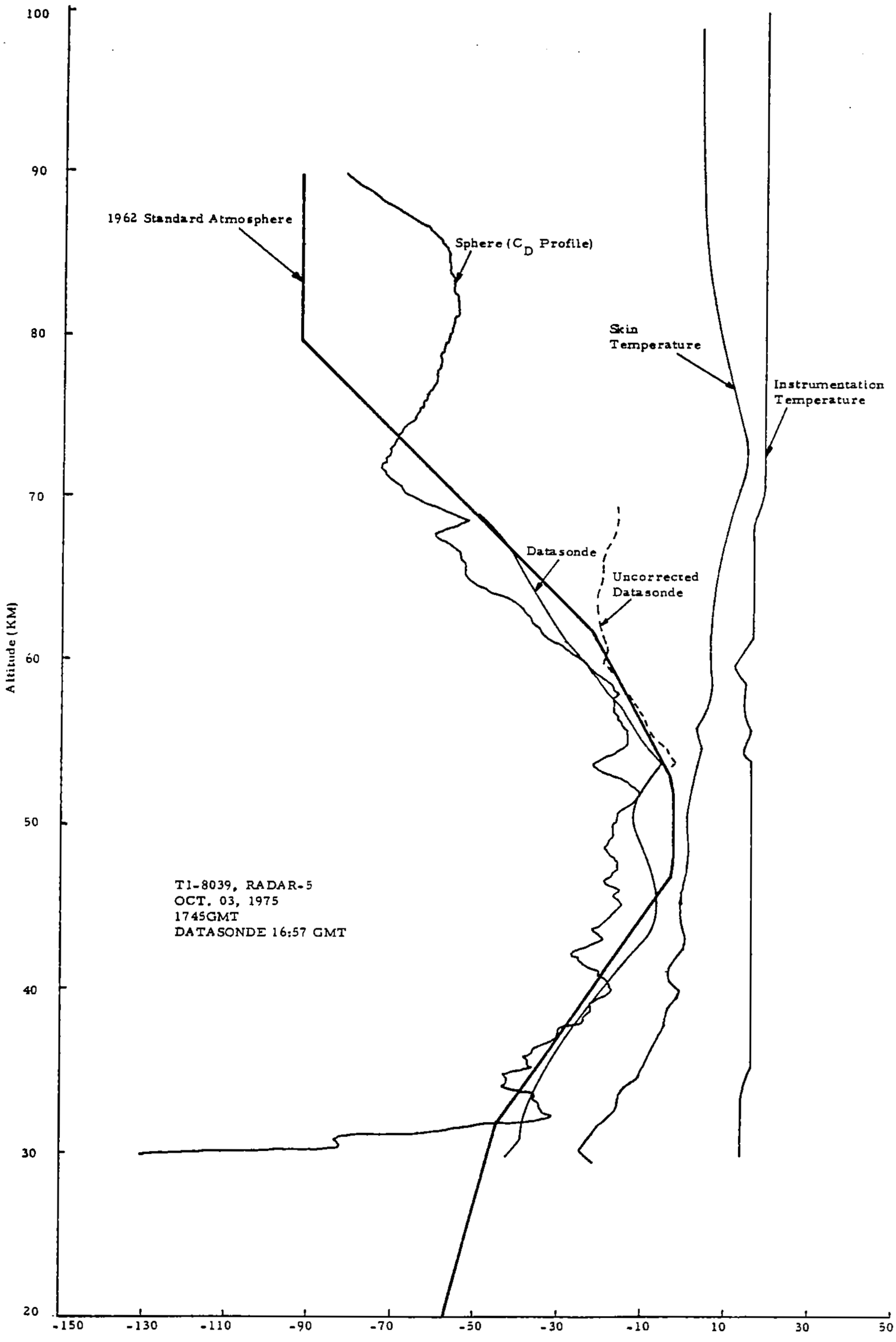


Figure 9. Temperature Profiles From Flight #1.

radiant heating. Above 55 Km the skin temperature is much warmer due to aerodynamic heating.

b. The skin temperature profile shows details repeatable in the sphere C_D profile. The temperature perturbation at 42 Km is seen in both profiles but not in the datasonde profile. Therefore it is a real temperature fluctuation that apparently was not present at the time of the datasonde launch.

c. Potential exists for measuring vertical winds. From 40 to 30 Km both the datasonde and skin temperature profiles show the same trend. The sphere (C_D) however, shows perturbations at 32.5 and 35 Km. These are most probably vertical winds. Also the temperature oscillation at 54 Km in the sphere C_D profile is also caused by vertical winds since it does not appear in the skin temperature or datasonde profiles.

d. From 40 to 55 Km the skin and sphere C_D profiles show very similar trends. The datasonde shows a different trend which probably reflects a changing atmosphere over a 48 minute time span.

e. Above 55 Km the uncorrected (no radiation or aerodynamic heating corrections) datasonde profile shows slow divergence from the skin temperature profile. This indicates that the aerodynamic temperature corrections for deducing ambient temperatures from sphere skin temperature are slightly larger than the aerodynamic corrections for the datasonde. This would suggest decreased accuracy in deriving ambient temperatures from sphere skin temperatures above 55 Km.

f. The instrumentation temperature remains remarkably constant throughout the flight. This may reflect the location of the potted thermistor within the RTV of the instrumentation package and/or its proximity to heat generating components.

g. If radiant and aerodynamic heating correction terms can be calculated with sufficient accuracy it may be possible to deduce ambient temperature from skin temperature. The potential is especially encouraging below 60 Km where aerodynamic heating is small.

h. Skin temperature measurements were made at a point 90° from the south pole of the sphere. The relative air velocity observed at this location is greater than the free stream velocity of the sphere. Consequently the aerodynamic heating observed by the thermistor at this location is greater than if the thermistor were placed at a more desirable location. In order to deduce ambient temperature from skin temperature it is desirable to have a small aerodynamic heating term above 60 Km. Several launches were designed to provide a more desirable location of temperature measurements on the skin of the sphere.

i. The return signal from the radar track of the sphere shows signal dropouts whenever it views a a clear gore in the sphere. Thus, two signal dropouts occur per revolution of the sphere. The AGC radar chart observed the signal fluctuation so that the spin rate of the sphere could be deduced during descent. The spin rate immediately after ejection was approximately three revolutions per second. By 50 Km its spin rate was less than one revolution per second.

j. The effect of skin temperature on the drag coefficient was found to be less than 1-1/2%. Using figures from Reference 3 for $2 < \text{Mach} < 4$ and extrapolation of these figures for Mach < 2, the change in C_D as a function of the ratio of skin temperatures to free stream temperatures was calculated. At 90 Km the change in C_D was a maximum of 1-1/2%. Below 85 Km the change in C_D was less than 1%.

Flight #2

Four-Channel System:	Viper Dart Rocket, Sphere Mass = 184 grams
Three Thermistors: (see Figure 8)	Veco - south pole metalized gore Fenwall - 90° metalized gore YSI - north pole metalized gore
Accelerometer:	Imbedded in instrumentation - south pole
Launch Date:	07 January 1976
Launch Time:	18:54 Zulu

Test Objectives:

- To measure the acceleration trace so as to determine sphere rotation rate, its wobble, and its acceleration time history which could be compared to radar tracking acceleration.
- To measure the skin temperature distribution at different locations on the sphere.
- To compare time constants of the different thermistors.

Results: No telemetry data was received from the transmitter. The sphere ejected, inflated and was tracked by radar to collapse at 35 Km. Wind, temperature, pressure, and density profiles were generated from the computer reduction of tracking data.

Flight #3

Four-Channel System:	Viper Dart Rocket, Sphere Mass = 184.4 grams
Three Thermistors: (see Figure 8)	YSI - adjacent to pressure transducer YSI - 90° metalized gore YSI - 90° clear gore
Differential Pressure Transducer:	Imbedded in instrumentation - south pole
Launch Date:	07 January 1976
Launch Time:	19:58 Zulu
Test Objectives	• To observe internal pressure history of the sphere, especially during inflation and when penetrating Mach 1. • Measure difference between skin temperature on metalized and clear gores.
Results:	No telemetry data was received from the transmitter. The sphere ejected, inflated, and was tracked by radar to collapse at 34 Km. Wind, temperature, pressure, and density profiles were generated from the computer reduction of tracking data.

POST FLIGHT EVALUATION

An evaluation of the possible cause of failure of telemetry reception from Flight #2 and Flight #3 was made shortly after the launches. The following list was generated.

a. Failure of both switches to turn on the transmitters.

b. Failure of clock mechanism in four-channel systems (two-channel system does not have a clock).

c. Failure of both transmitters.

d. Failure of batteries or battery leads in both systems.

e. Failure or breakage of all thermistors, accelerometer, and transducer.

f. Breakage of wire leads in both systems during packaging.

g. Failure of critical components, such as transmitter, clock or leads, resulting from ejection forces.

h. Antenna wire breakage on both spheres.

i. Battery failure due to switch activation before launch.

j. Transmitter frequency shift outside of range of receiver.

k. Failure of receiver to acquire signal.

l. Combination of the above, i.e., sphere failures resulted from different causes.

The telemetry failures for Flight #2 and Flight #3 could not be positively attributed to any of these causes, however, some appear more likely than others. A discussion of each follows.

a. In the successful launch (Flight #1) the switch worked properly. Moreover, there is a two wire redundancy built into the switch. Also, inflation with isopentane indicates the cap traveled to the "on" switch position. For failure, the cap would have had to retract from the "on" position.

b. If the clock is sensitive to ejection forces or cold temperatures, failures could result. Post-flight tests of a clock performance at -30°C was satisfactory. An ejection shock test also resulted in no clock failure (see Section 1.11.3).

c. Failure of both transmitters. The transistor is performing at its lowest operating range of power and voltage. It is designed for power input up to 5 watts at 15 volts. It is activated by 5 volts with approximately 200 milliwatts. However, the identical transistor performed well with the first launch. Post flight tests of other transistors uncovered none with substantively better performance (see Section 1.11.7).

d. It is unlikely that both battery sets failed. Success in the first launch indicated that the batteries can function at cold atmospheric temperatures. Battery leads inside RTV could have been broken in packaging.

e. The system is designed so that failure of any data channel will not effect transmission of other channels. It is extremely unlikely that all sensors failed so that no data was transmitted.

f. The diameter of the instrumentation capsule is slightly less than 2.5 centimeters. The room available inside the staves is exactly 2.54 centimeters. Pressure on the instrumentation package is required to package the sphere inside the staves. It is conceivable that this force expands the RTV, pushing boards slightly further apart and breaking lead wires. However, a post flight packing test of another four-channel system showed no damage whatsoever due to packaging (see Section 1.11.5).

g. The successful launch of Flight #1 indicates that transmitter and leads can withstand the ejection forces. Simulated post flight shock tests with another four-channel system showed no damage (see Section 1.11.3).

h. Antenna wire breakage on both spheres is possible but not likely. Sufficient slack was left between attachment points to allow for anticipated motion of capsule.

i. Switch could be activated by contact of metalized skin with both cap and capsule. A piece of clear mylar is taped over cap to insulate cap from skin. The mylar, however, has a small hole cut in it to allow gas to escape through top of cap. The conductivity test indicated that contact is possible, though unlikely, through aluminized skin from this point to capsule (see Section 1.11.4). On all launches after Flight #3, a piece of tape was used to insulate that cap from electrical contact with the skin.

j. Transmitter frequency shift outside of range of receiver is not likely since receivers have wide frequency capability and the first Flight (Flight #1), with the same transmitter, did not produce a large frequency shift. Furthermore, the Flight #2 and Flight #3 systems were tuned to rather different frequencies, 230 MHz and 260 MHz.

k. Failure of receiver to acquire signal is not likely since personnel are well qualified and experienced.

l. A combination of the possible causes is most likely.

No definite cause could be established for the failures of Flights #2 and #3. Since the successful Flight #1 was a two-channel system, it was decided that a two-channel launch should be included in the next set of flights.

Flight #4

Two-Channel System:	Viper Dart Rocket, Sphere Mass = 168.5 grams
Two Thermistors: (see Figure 8)	Fenwall - south pole Fenwall - north pole
Launch Date:	21 April 1976
Launch Time:	15:30 Zulu
Test Objectives	• Retest performance of two-channel systems vs. four-channel. • Obtain skin temperature measurements at sphere locations of maximum and minimum aerodynamic heating.
Results:	No telemetry data was received from the transmitter. The ejection of the sphere resulted in catastrophic sphere failure. The deflated or torn balloon was tracked by radar to 30 Km. Even though balloon malfunction occurred, some telemetry data should have been received unless the instrument package also failed.

Flight #5

Four-Channel System:	Viper Dart Rocket, Sphere Mass = 178.5 grams
Four Thermistors:	YSI - 40° clear gore YSI - 40° metalized gore Fenwall - 40° metalized gore VECO - 40° metalized gore
Launch Date:	22 April 1976
Launch Time:	15:30 Zulu
Test Objectives	• Measure skin temperature at location (40° from south pole) where air velocity over sphere equals free stream sphere velocity. • Measure influence of thermistor time constant on measurement of skin temperature. • Measure difference between skin temperature on metalized and clear gores.

Results:	No telemetry data was received from the transmitter, the sphere ejected, inflated and was tracked by radar to collapse at 34 Km. Winds, temperature, pressure and density profiles were generated from the computer reduction of tracking data.

POST FLIGHT EVALUATION

After an exhaustive search and evaluation of the possible failure modes for Flights #2, #3, #5, it was thought that the most likely cause of failure was the inability of the cap to remain in electrical contact with the spring clip. Perhaps the cap, after puncturing the capsule, retracts back over the spring clip. This could result from the restoring force of the compressed mylar, from the despinning of the cap and capsule, or from some other causes. It was decided that the remaining two systems would be launched with a second switch wired in parallel with the cap switch. Section 1.12 describes the incorporation of a microswitch and a magnetic reed switch into the remaining two systems.

Flight #6

Four-Channel System:	Super-Loki Rocket, Sphere Mass = 187.0 grams.
Four Thermistors: (see Figure 8)	Fenwall - south pole metalized gore Fenwall - 40° from south pole metalized gore Fenwall - 40° from south pole clear gore Fenwall - north pole
Launch Date:	2 June 1976
Launch Time:	15:23 Zulu
Test Objectives	• Measure skin temperature at significant locations on the sphere. • Measure difference between skin temperature on metalized and clear gores.
Results:	No telemetry data was received from the transmitter. The sphere ejected, inflated and was tracked by radar to collapse at 32 Km Wind, temperature, density and pressure profiles were generated from the computer reduction of tracking data.

POST FLIGHT EVALUATION

Immediately after failure of the sixth launch, it was decided not to attempt a launch of a seventh and final system. It was highly unlikely that both switches failed on Flight #6. No reasonably appealing cause of the failures remained. It appears that the most practical way of determining the failure mode of Flights #2 through #6 is to recover a sphere after its flight. It is suggested that the last system be launched either at White Sands Missile Range or at Wallops Flight Center and a sphere recovery be attempted.

SECTION 2
GROUND TESTS OF PASSIVE SPHERES

2.1 SHELF LIFE TESTS

Six sphere assemblies were removed from viper dart systems that had been in storage for two years. Tests were performed on the spheres to determine if deterioration in sphere integrity resulted from storage over extended periods of time. Of the six sphere systems, one sphere was inflated to test for leaks. The other systems were inspected without inflation. The capsules were removed from these spheres for further observation. Results are as follows. The sphere on which the inflation test was performed was carefully removed from the staves, unfolded and inflated. A video tape was made of the inflation process. Two irregularities were found. A rubber spacer that separates the sphere from the insulated stave walls was not in its designated slot. No damage was apparent from this misalignment and this is <u>not</u> considered a significant irregularity. During inflation a serious problem was uncovered. Apparent sticking together of the skin at a very small point caused a slit to develop. The slit was approximately 0.16 cm wide and 1.6 cm long. The apparent cause of the sticking was a small amount of a foreign substance on the surface of the sphere. Photographs were taken to determine if part of the foreign substance remained on the slit. The photos proved inconclusive. It was suspected that the foreign substance was some type of adhesive.

The other five spheres were removed from the staves, unfolded and examined for skin defects. On one of the spheres a partial tape failure was observed. When the sphere was unpackaged, a strip of heat sensitive tape, approximately 0.3 cm long, was not adhering to either of the two gores of which it was to bond. It appeared that this segment of tape had never been heated to a temperature sufficient to bond it to the gores. No skin or tape failures were found on the remaining four spheres.

The isopentane inflation capsules were removed from each of the six spheres for observation. Two of the capsules had already been punctured by the cap pin and contained no isopentane. The other four capsules were unruptured and all appeared to contain approximately the same amount of isopentane. The capsule size (approximately 2 cm diameter X 12 cm length) contains sufficient volume for 36 cubic centimeters. It is unknown why a large capsule size was used to contain only 20 cubic centimeters of isopentane.

The cause of the puncture of the two empty isopentane capsules could not be determined. Since no recollection of sphere loading or unloading problems was available, it could not be determined if the puncture of the capsule occurred in packaging, loading or unloading of the sphere systems.

2.2 TEST OF DELAY CAPSULE

A test was also made on an inflation capsule obtained from a Super-Loki sphere system that contained a pyrotechnic device which delays the inflatant release for six seconds after ejection. The capsule test was made under room temperature and pressure conditions. The activation pin that ignites the pyrotechnic delay was depressed. The resulting delay, before release of inflatant, was 15 seconds rather than the six second delay indicated in Reference 4. As the inflatant gas escaped through the small capsule orifice, the orifice, at times, became clogged due to freezing of the inflatant. By applying a small amount of heat the orifice opened and gas again escaped. Approximately three minutes were required for all gas to escape from the capsule. This experiment was performed under a room temperature and atmospheric pressure environment and may not perform in the same manner under the very low pressure conditions at ejection. Nevertheless the results suggest that a further look at the possibility of some inflatant remaining in the capsule throughout the flight be made.

2.3 CHAMBER TESTS

Inflation tests of three spheres were made in the seven foot Wallops vacuum chamber. The inflation capsule was removed from each sphere and an alternate inflation source inserted. One test sphere was designed for inflation by residual air trapped inside the sphere. An empty isopentane capsule and a 2.54 cm X 7.62 cm cylindrical piece of polyurathane foam were sealed within the sphere to entrap the air needed to inflate the sphere. The capsule plus foam occupies about all excess space available for air entrapment. A second sphere was packaged with five cylindrical pieces of charcoal approximately 1.9 cm diameter X 4.45 cm length. If rapid inflation of the first sphere by residual air caused failure, it was anticipated that a slow outgassing material such as charcoal would solve the problem. The third sphere was packaged containing an absorbent type paper saturated with 20 cc of isopentane. This test was designed to analyze the potential for sphere inflation by free isopentane.

Each sphere was packaged in plastic staves, of the same inside diameter as the metal staves used for packaging in the dart. The staves were then placed in an ejection tube and sealed (see Figure 10). To eject the sphere from a vertically hanging position within the vacuum chamber an electric current was passed through the retaining wire which severed the wire. This allowed the weight to fall free for approximately 20 cm until a second slack wire attached to the plug became taut and pulled the plug and the staves from the tube. Once the staves were extracted from the tube the sphere expanded freely to its full one meter diameter.

The vacuum chamber inflation tests were designed to test two items. One possible failure mode at ejection is the rapid sphere inflation due to simultaneous vaporization of isopentane and expansion of residual air remaining in the sphere after packaging. Speculation that inflation forces resulting from rapid sphere expansion caused the sphere to rip or tear has led to the incorporation of a pyrotechnic delay into the super loki system that retards isopentane release until six seconds after ejection. The vacuum chamber tests described above, using large amounts of residual air and unconstrained isopentane served to test the structural integrity of the sphere during inflation. The second purpose of the chamber tests was to assess the feasibility of inflating the passive spheres by means other than puncturing an isopentane capsule.

Results from the chamber tests are as follows. Three spheres were suspended from the top of the vacuum chamber with sufficient separation so that no interference between systems occurred during inflation. The chamber was evacuated to a pressure altitude of 125 Km and the three systems were individually inflated by remotely burning each retaining wire. All three spheres inflated on command and remained inflated. No tears, rips or failures of any type were observed from the rapid sphere inflation process. After all three spheres were successfully inflated recompression of the chamber began. Recompression was scheduled to coincide timewise with the pressure profile experience by a falling sphere. Recompression went exactly as

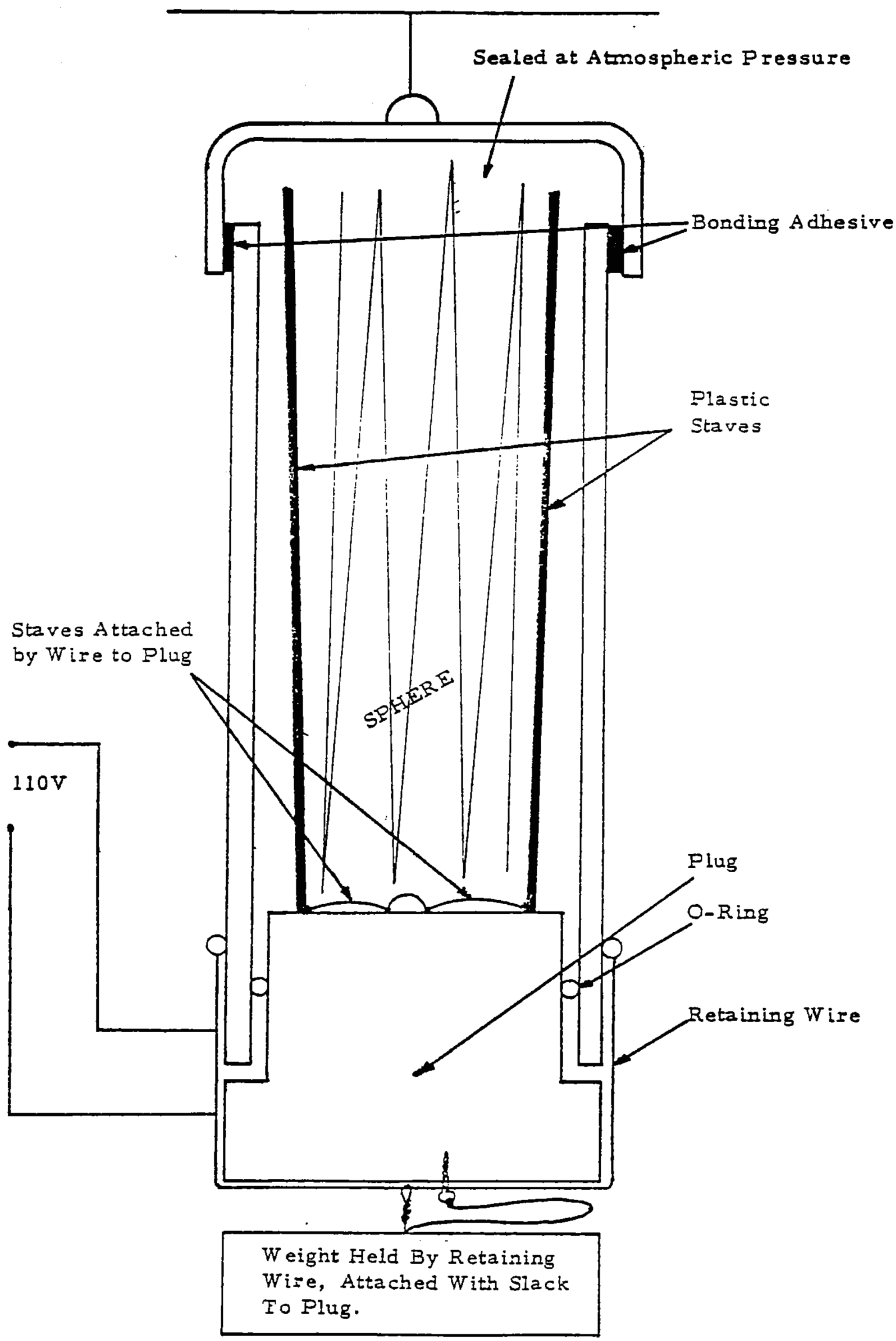


Figure 10. Sphere Packaged in Ejection Tube.

planned until about 67 Km when additional valves in the chamber had to be opened to allow a more rapid reentry of air. The lines from these valves had not been purged and a surge of air produced instantaneous recompression of the chamber. The spheres were blown around within the chamber and the sphere with five pieces of charcoal was ripped. Outgassing of air from the charcoal prevented an attempted rapid re-evacuation of the chamber by restarting of the vacuum pumps. Thus the experiment was terminated. Movies at 200 frames per second were taken of each sphere inflation and every 30 seconds during recompression. Viewing of the high speed movies verified that all spheres inflated properly and remained inflated throughout recompression until the experiment terminated at 67 Km. At 67 Km all spheres were still inflated. These chamber tests gave no reason to suspect that rapid sphere inflation at ejection is a cause for catastrophic sphere failure. Since the experiment terminated prematurely, the collapse altitude for each of the inflation techniques could not be determined.

SECTION 3
SUMMARY AND CONCLUSIONS

Even though only one of the six launches of instrumented spheres produced telemetry data, many of the objectives of the program were achieved. The temperature data from Flight #1 established the practicality of miniaturized instrumentation to transmit data from rocket borne meteorological sensors. Potential utility of sphere skin temperature data has also been established. Other observations and experimental results provided new knowledge about packaging and performance of the passive sphere system. Specific conclusions and observations resulting from this program are as follows.

a. The successful launch of a two-channel system proved that it is possible to design and fabricate a subminiature sensing and telemetry circuit (2.22 cm diameter X 7.62 cm length, ≈ 80 grams) that can withstand launch spin and ejection forces of a Viper Dart rocket and transmit at a range in excess of 100 Km for at least the duration of a 15 minute flight.

b. The skin temperature profile obtained from 100 - 30 Km shows there is sufficient heat available for complete vaporization of isopentane by at least 100 Km.

c. Comparison of the skin temperature to the ambient (obtained from datasonde and sphere via drag coefficients) temperature shows that below 60 Km both profiles are of the same shape with the skin temperature profile biased 17° to 20° warmer. Thus the skin temperature "feels" changes in the ambient temperature.

d. Direct measurement of ambient temperature from skin temperature may be possible below 60 Km by describing skin temperature in terms of radiant, aerodynamic and ambient heat input in a manner similiar to that presently used with datasonde sensors.

e. The influence of skin temperature on drag coefficient is minimal.

f. Six spheres removed from Viper Dart staves after being stored for two years indicated some potential failure modes.

i) One of the spheres, while being inflated, developed a tear due to sticking of the mylar, probably from the pressure of an adhesive.

ii) Two of the spheres contained no isopentane due to capsules that had already been punctured by the cap. This could have occurred during loading or downloading of the system in the Dart vehicle.

iii) At least one sphere had a 15-20 cm segment of tape that did not adhere to the sphere.

g. The test of a Super Loki six-second inflation delay capsule under room temperature and pressure conditions resulted in an actual 15 seconds delay before the release of the inflatant. Several times during vaporization of the inflatant from the capsule the orifice froze shut. Three minutes were required before all inflatant escaped from the capsule. Though this test was not performed under the actual low pressure flight conditions of the sphere, it is recommended that further consideration be given this problem.

h. In evacuating and packaging various spheres, it was found that none of the spheres were completely airtight under high vacuum, or high superpressure conditions. However, all spheres that inflated during an actual launch remained inflated to at least 35 Km. Thus, gas loss at 10 mb superpressure was minimal.

i. Chamber tests of sphere inflation with residual air and isopentane gave no indication that rapid sphere inflation at ejection is the cause of catastrophic sphere failure. All three spheres inflated properly without structural failure.

j. Chamber tests of three spheres with simple and reliable inflation devices; residual air, residual air entrapped in charcoal, and liquid isopentane saturated in an absorbent paper, were inconclusive. All spheres inflated properly but a chamber failure during recompression at 67 Km pressure-altitude prevented the determination of collapse altitude for each sphere.

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16. Abstract
Instrumentation has been developed for the high altitude inflatable sphere to measure its skin temperature, acceleration and internal pressure. The sphere without instrumentation has routinely been used over the past 10 years to provide measurements of winds, density, temperature and pressure between 100 Km and 30 Km altitude. With the miniaturized instrumentation package onboard, the system offers the potential for providing additional meteorological information as well as a better understanding of sphere performance and dynamics during its descent. Of the six launches of instrumented spheres only one provided telemetry data. However, many of the objectives of the program were achieved.

Some of the results are as follows. The successful performance of a two-channel instrumentation package proved that it is possible to fabricate a subminiature sensing and telemetry circuit (2.22 cm diameter X 7.6 cm length) that can withstand the launch, spin and ejection forces associated with the Viper Dart rocket and transmit at a distance in excess of 100 Km. Temperature data obtained from this launch gave evidence that: a) there is sufficient heat available in the sphere for complete vaporization of isopentane inflatent; b) the skin temperature of the sphere has minimal effect on the drag coefficient; and c) it may be possible to deduce ambient temperature from skin temperature, with reasonable accuracy below 60 Km.

Tests were also performed on inflatable spheres in the Wallops vacuum chamber to study problems that have occurred with sphere inflation. Tests on three spheres gave no indication that rapid sphere inflation can cause sphere failure. Tests of residual air as a sphere inflatent were inconclusive due to failure of the vacuum pump during recompression. The test of a Super Loki type inflation capsule uncovered difficulties with the inflatent gas escaping from the capsule due to ice buildup at the orifice. Further tests of the inflation capsule as well as residual air as an inflatent are recommended.

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